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1.0 INTRODUCTION

Tetra Tech EM Inc. (TtEMI) prepared this revised modeling report to support remedial action at the Lockwood Solvent Groundwater Plume Site (LSGPS). This report documents revisions to the vadose zone modeling presented in Appendix D of the Feasibility Study (TtEMI 2004). Revisions were required to address errors and inconsistencies in the modeling. The modeling results provide guidance for identifying vadose zone concentrations that may generate leachate concentrations in groundwater that exceed maximum contaminant levels (MCL) at the LSGPS. The modeling focused on soil and subsurface unconsolidated materials in the unsaturated zone (vadose zone soil) contaminated with the chlorinated solvents tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE) and vinyl chloride (VC), herein referred to as contaminants of concern (COC). The results of the modeling have been used to define remediation goals for the Record of Decision.

1.1 OBJECTIVES

The objectives of the revised modeling were to correct errors and inconsistencies and calculate revised soil remediation goals at the Brenntag and Beall Source Areas. These revisions primarily included correcting a layer thickness error discovered in the infiltration model and incorporating consistent vadose soil properties in the modeling. Site data did not indicate significant differences between vadose soil characteristics at the two source areas. Therefore, the revised modeling at both the Brenntag Source Area and the Beall Source Area used silty clay loam parameters in determining infiltration rates, dilution factors and cleanup levels.

As in the earlier modeling, cleanup levels were determined through a two-stage modeling process. The first stage involved the calculation of LSGPS-specific infiltration rates using a vadose zone leaching model. The second stage involved calculation of area-specific dilution factors, leachate concentrations, and soil remediation levels.

2.0 MODELING APPROACH

The modeling approach consisted of (1) simulating the hydrologic cycle to determine the amount of recharge occurring to the aquifer, (2) modeling of potential COC leaching within the unsaturated zone,

and (3) calculation of soil remediation levels. The revised modeling approach is discussed in detail in the following sections.

2.1 HYDROLOGIC CYCLE MODELING

The annual average hydrologic cycle for the vadose zone was simulated using the SESOIL model included in Waterloo Hydrologic Inc. UnSat Suite version 2.2. A description of SESOIL is presented in Appendix D of the Feasibility Study (TtEMI 2004). The model settings for the LSGPS simulations include four layers, a simulation length of 10 years, and a site latitude of 46°. Simulation time is based upon time required for steady state conditions to be met. The layers were modeled as silty clay loam at both the Brenntag Source Area and the Beall Source Area. The subroutine that simulates soil erosion and contaminant washload was turned off as a conservative assumption because no site-specific runoff or erosion information was available.

The climatic variables for each month that were input into the model included mean air temperature, mean cloud cover, mean relative humidity, short wave albedo, mean precipitation, mean storm duration, number of storms, and length of rainy season (Attachment 1). The climate data was initially prepared using a weather generator database included in the SESOIL model. The nearest location in the database was for Billings, Montana located approximately five miles to the west of the LSGPS. Monthly mean temperature and precipitation data were subsequently acquired from National Oceanographic and Atmospheric Administration (NOAA) data for the Billings, Montana water treatment facility (NOAA 2001) and used as input into the model.

The SESOIL model includes soil parameters for a number of generic soil types. A review of available soil boring logs and soil data from the Appendix D and Appendix G of the Remedial Investigation Report (TtEMI 2003) suggests that the unsaturated zone at both the Brenntag Source Area and Beall Source Area is composed of a silty clay loam.

The results of the modeling are presented in Attachment 1. The Brenntag source area model simulations resulted in an annual groundwater recharge of 3.931 centimeters per year (cm/yr). The Beall source area model simulations resulted in an annual groundwater recharge of 3.397 cm/yr.

2.2 SOIL REMEDIATION GOAL MODELING

Soil remediation goals were calculated using the procedures described in the U.S. Environmental Protection Agency's (EPA) "Soil Screening Guidance: User's Guide" (EPA 1996 and EPA 2001). Attachment 2 presents a summary of the input parameters and their sources used for the Brenntag Source Area and the Beall Source Area. To complete the leachate concentration calculations, the chlorinated solvent concentration in groundwater was set at the remediation goal provided by the Montana Department of Environmental Quality (DEQ 2002). Source area-specific dilution factors were calculated and multiplied by the chemical-specific remediation goal. The source area-specific dilution factors were calculated using the following equations and parameters (EPA 1996):

$$\text{Dilution Factor (unitless)} = 1 + [K (ii) d] / [I (L)]$$

Where:

- K = hydraulic conductivity (m/yr)
- ii = hydraulic gradient (m/m)
- d = depth of mixing zone (m)
- I = infiltration rate calculated using SESOIL (m/yr)
- L = source length parallel to groundwater flow (m)

And:

$$\text{Depth of Mixing Zone (m)} = [0.0112 (L)^2]^{0.5} + d_a \{1 - \exp[(-L(I)) / (K(ii)d_a)]\}$$

Where:

- K = hydraulic conductivity (m/yr)
- ii = hydraulic gradient (m/m)
- d_a = aquifer thickness (m)
- I = infiltration rate calculated using SESOIL (m/yr)
- L = source length parallel to groundwater flow (m)

Sources of all parameters are identified in Attachment 2. The infiltration rate was calculated with the SESOIL model using the parameters from the Appendix E.

The pore water concentration corresponding to the maximum leachate concentration was then used to calculate a maximum target chemical concentration in soil (remediation goal) within the vadose zone using the following equation (EPA 1996):

$$\text{Soil Remediation Goal} = C_w \{K_d + [(\Theta_w + \Theta_a H')/\rho_b]\}$$

- C_w = Soil Leachate Concentration (mg/L). Calculated by multiplying the WQB-7 groundwater standard (DEQ 2002) by the dilution factor.
- K_d = Soil-water Partitioning Coefficient.
- K_{oc} = Soil Organic Carbon/Water Partitioning Coefficient.
- F_{oc} = Fraction Organic Carbon in Soil
- Θ_w = Water-filled Soil Porosity
- Θ_a = Air-filled Porosity
- ρ_b = Dry Soil Bulk Density (Kg/L)
- H' = Henry's Law Constant.

Results of these calculations for the Brenntag Source Area can be found in Table 2-1. Results for the Beall Source Area are found in Table 2-2.

TABLE 2-1
BRENTAG SOURCE AREA CALCULATED CONCENTRATIONS
LOCKWOOD SOLVENT GROUNDWATER PLUME SITE

	DEQ Groundwater r MCL ^a (mg/l)	Maximum Allowable Leachate Concentration (mg/l)	Maximum Soil Concentration in Vadose Zone (mg/kg)
Tetrachloroethene	0.005	0.697	0.654
Trichloroethene	0.005	0.697	0.720
Cis-1,2-dichloroethene	0.070	9.757	4.898
Vinyl chloride	0.002	0.279	0.157

Notes:

a Circular WQB-7, Montana Numeric Water Quality Standards (DEQ 2002)

mg/kg milligrams per kilogram

mg/l milligrams per liter

DEQ Montana Department of Environmental Quality

MCL Maximum Contaminant Level

TABLE 2-2

**BEALL SOURCE AREA CALCULATED CONCENTRATIONS
LOCKWOOD SOLVENT GROUNDWATER PLUME SITE**

	DEQ Groundwater MCL ^a (mg/l)	Maximum Allowable Leachate Concentration (mg/l)	Maximum Soil Concentration in Vadose Zone (mg/kg)
Tetrachloroethene	0.005	0.234	0.219
Trichloroethene	0.005	0.234	0.241
Cis-1,2-dichloroethene	0.070	3.274	1.636
Vinyl chloride	0.002	0.094	0.053

Notes:

a Circular WQB-7, Montana Numeric Water Quality Standards (DEQ 2002)

mg/kg milligrams per kilogram

mg/l milligrams per liter

MCL Maximum Contaminant Level

DEQ Montana Department of Environmental Quality

3.0 CONCLUSIONS

Vadose soil modeling was revised to correct errors in the infiltration rate modeling and to use consistent soil properties for both the Brenntag Source Area and the Beall Source Area. Modeling was used to estimate the concentrations of the chlorinated solvents PCE, TCE, cis-1,2-DCE, and VC sorbed to vadose zone soil that would result in soil leachate concentrations causing an exceedence of their associated groundwater MCLs. Parameter inputs to the model were selected based on site data or from default parameters provided by the model.

REFERENCES

- DEQ. 2002. "Circular WQB-7 Montana Numeric Water Quality Standards". Montana Department of Environmental Quality.
- National Oceanic and Atmospheric Administration. 2001. "Climatology of the United States No. 81, Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1971 – 2000. National Climatic Data Center, Asheville, North Carolina.
- TtEMI. 2003. "Remedial Investigation Report for the Lockwood Solvent Groundwater Plume Site." Prepared for the Montana Department of Environmental Quality. June 2003.
- TtEMI. 2004. "Final Feasibility Study Report, Lockwood Solvent Ground Water Plume Site." Prepared for the Montana Department of Environmental Quality. July.
- EPA. 1996. "Soil Screening Guidance: User's Guide." Publication 9355.4-23. July.
- EPA. 2001. "Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites." Publication OSWER 9355.4-24.

ATTACHMENT 1

SESOIL MODEL INPUT FILE AND RESULTS

ATTACHMENT 2

SOIL REMEDIATION GOAL MODELING RESULTS

SESOIL MODEL

Model Settings for Brenntag and Beall

Case Settings

Parameter	Value	Units
Number of Layers	4	(-)
Simulation Length	3652.6	(days)
Site Latitude	46	(-)
Washload Simulation	No washload transport	(-)
Spill Type	continuous	(-)
Month to load initial concentrations	1	(-)

Climate

Year	Parameter	Unit	OCT	NOV	DEC	JAN	FEB	MAR
1	Mean Air Temperature	Degrees F	50.3	36	27.5	25.3	31.3	39.3
1	Mean Monthly Cloud Cover	-	0.4	0.4	0.4	0.4	0.4	0.4
1	Mean Monthly Relative Humidity	-	0.76	0.76	0.76	0.76	0.76	0.76
1	Short Wave Albedo	-	0.2	0.2	0.3	0.3	0.3	0.3
1	Mean Monthly Evapotranspiration Rate	cm/day	0	0	0	0	0	0
1	Monthly Precipitation	in	1.32	0.64	0.57	0.62	0.49	0.87
1	Mean Storm Duration	days	0.5	0.5	0.6	0.6	0.55	0.5
1	Number of Storms	-	4	4.5	5	5	6	6
1	Length of Rainy Season	days	30.4	30.4	30.4	30.4	30.4	30.4


Year	Parameter	Unit	APR	MAY	JUN	JUL	AUG	SEP
1	Mean Air Temperature	Degrees F	48.3	57.4	66.2	72.3	71.3	61
1	Mean Monthly Cloud Cover	-	0.4	0.4	0.4	0.4	0.4	0.4
1	Mean Monthly Relative Humidity	-	0.68	0.68	0.68	0.72	0.72	0.72
1	Short Wave Albedo	-	0.2	0.2	0.2	0.2	0.2	0.2
1	Mean Monthly Evapotranspiration Rate	cm/day	0	0	0	0	0	0
1	Monthly Precipitation	in	1.55	2.39	1.98	1.19	0.92	1.42
1	Mean Storm Duration	days	0.5	0.45	0.4	0.35	0.3	0.35
1	Number of Storms	-	6	5.5	5	5	4.5	4.5
1	Length of Rainy Season	days	30.4	30.4	30.4	30.4	30.4	30.4

Source: Mean Air Temperature and Monthly Precipitation from National Climatic Data Center 1971 to 2000 monthly normals

Evapotranspiration set to zero as a conservative assumption.

All others are model default values for Billings, Montana

Profile Structure for Beall

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
 Silty Clay Loam	0.0000	-1219.2000	1219.2000

Source: Silty Clay Loam based on bore hole logs and sieve analyses, RI Report, Appendix D and Appendix G

Layer thickness from FS Report, Appendix E


Silty Clay Loam

Soil Parameters

Parameter	Value	Units
Dry Bulk Density	1.4	(g/cu.cm)
Intrinsic Permeability	8.5E-11	(cm2)
Disconnectedness Index	10	(-)
Effective Porosity	0.27	(-)
Fraction Organic Content	0.2	(%%)
Cation Exchange Capacity	27	(mg-equiv/100g)
Freundlich Exponent	1.2	(-)

Source: Default parameters for silty clay loam in the WHI UnSat Suite Plus

Profile Structure For Brenntag

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
 Silty Clay Loam	0.0000	-304.8000	304.8000

Source: Silty clay loam based on bore logs, RI Report, Appendix D

Layer thickness from FS Report, Appendix E

Silty Clay Loam

Soil Parameters

Parameter	Value	Units
Dry Bulk Density	1.4	(g/cu.cm)
Intrinsic Permeability	8.5E-11	(cm2)
Disconnectedness Index	10	(-)
Effective Porosity	0.27	(-)
Fraction Organic Content	0.2	(%%)
Cation Exchange Capacity	27	(mg-equiv/100g)
Freundlich Exponent	1.2	(-)

Source: Default parameters for silty clay loam in the WHI UnSat Suite Plus

SESOIL Infiltration Rate Results

Model Output Beall Steady State Conditions

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
GRW. RUNOFF (CM)	0.187	0.218	0.267	0.360	0.375	0.307	0.313	0.349	0.346	0.280	0.208	0.187

Total Potential Groundwater Recharge = 3.397 cm/yr (0.03397 m/yr)

Model Output Brenntag Steady State Conditions

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
GRW. RUNOFF (CM)	0.178	0.424	0.630	0.803	0.493	0.212	0.231	0.290	0.268	0.170	0.100	0.132

Total Potential Groundwater Recharge = 3.931 cm/yr (0.03931 m/yr)

Beall

Soil Remediation Goal Calculations

Equation 10 (EPA 1996)	WQB-7 Standard	Cw mg/L	Koc	foc	Kd	Ow	Oa	H'	Pb	RG mg/kg
PCE	0.005	0.234	289	0.0018	0.520	0.394	0.149	0.754	1.215	0.219
TCE	0.005	0.234	364	0.0018	0.655	0.394	0.149	0.422	1.215	0.241
cis-1,1-DCE	0.07	3.274	86	0.0018	0.155	0.394	0.149	0.167	1.215	1.636
VC	0.002	0.094	57	0.0018	0.103	0.394	0.149	1.11	1.215	0.053

Ow Equation (EPA 1996)	n	1/(2b+3)	Ks	Ps
(Appendix A-2)	0.544	0.054	13	2.6625

Dilution Factor

Equation 11 (EPA 1996)	K	ii	d	I	L	Dilution Factor
	2490	0.0059	1.65	0.03397	15.24	46.77

Mixing Zone Depth

Equation 12 (EPA 1996)	L	da	I	K	ii	Mixing Zone Depth (d)
	15.24	7.62	0.03397	2491.3	0.0059	1.65

Parameters

Formula

Source

Cw = target soil leachate concentration (mg/L)	WQB-7 standard x dilution factor	EPA 1996
Kd = soil-water partition coefficient (L/kg)	Koc x foc	TtEMI 2004 (Appendix D)
Koc = soil organic carbon/water partition coefficient (L/kg)		TtEMI 2004 (Appendix D)
foc = fraction organic carbon in soil (g/g)		TtEMI 2004 (Appendix D)
Ow = water-filled soil porosity	$n \times (I/Ks)^{1/(2b+3)}$	EPA 1996
Oa = air-filled soil porosity	n-Ow	EPA 1996
H' = Henry's law constant		EPA 1996 (Table C-1)
Pb = dry soil bulk density (kg/L)		TtEMI 2003 (Appendix G)
n = total soil porosity	1-Pb/Ps	EPA 1996
b = soil-specific exponential parameter		EPA 1996 (Table A-2)
Ks = saturated hydraulic conductivity (m/yr)		EPA 1996 (Table A-2: Silty clay loam)
Ps = soil particle density (kg/L)		TtEMI 2003 (Appendix G)
K = aquifer hydraulic conductivity (m/yr)		TtEMI 2004 (Appendix E)
ii = hydraulic gradient (m/m)		TtEMI 2004 (Appendix E)
I = infiltration rate (m/yr)		Seasoil infiltration model
d = mixing zone depth (m)	Equation 12	EPA 1996
L = source length parallel to groundwater flow (m)		TtEMI 2004 (Figure 4-3)
da = aquifer thickness (m)		TtEMI 2004 (Appendix E)

EPA 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. July.

TtEMI 2003. Remedial Investigation Report, Lockwood Solvent Groundwater Plume Site. June.

TtEMI 2004. Feasibility Study Report, Lockwood Solvent Groundwater Plume Site. July.

Brenntag

Soil Remediation Goal Calculations

Equation 10 (EPA 1996)	WQB-7 Standard	Cw mg/L	Koc	foc	Kd	Ow	Oa	H'	Pb	RG mg/kg
PCE	0.005	0.697	289	0.0018	0.520	0.397	0.146	0.754	1.215	0.654
TCE	0.005	0.697	364	0.0018	0.655	0.397	0.146	0.422	1.215	0.720
cis 1,1-DCE	0.07	9.757	86	0.0018	0.155	0.397	0.146	0.167	1.215	4.898
VC	0.002	0.279	57	0.0018	0.103	0.397	0.146	1.11	1.215	0.157

Ow Equation (EPA 1996)	n	1/(2b+3)	Ks	Ps
(Appendix A-2)	0.544	0.054	13	2.6625

Dilution Factor

Equation 11 (EPA 1996)	K	ii	d	I	L	Dilution Factor
	7788	0.0066	4.0612	0.03931	38.1	139.38

Mixing Zone Depth

Equation 12 (EPA 1996)	L	da	I	K	ii	Mixing Zone Depth (d)
	38.1	6.7	0.03931	7788	0.0066	4.06

Parameters

Formula

Source

Cw = target soil leachate concentration (mg/L)	WQB-7 standard x dilution factor	EPA 1996
Kd = soil-water partition coefficient (L/kg)	Koc x foc	TtEMI 2004 (Appendix D)
Koc = soil organic carbon/water partition coefficient (L/kg)		TtEMI 2004 (Appendix D)
foc = fraction organic carbon in soil (g/g)		TtEMI 2004 (Appendix D)
Ow = water-filled soil porosity	$n \times (I/Ks)^{1/(2b+3)}$	EPA 1996
Oa = air-filled soil porosity	n-Ow	EPA 1996
H' = Henry's law constant		EPA 1996 (Table C-1)
Pb = dry soil bulk density (kg/L)		TtEMI 2003 (Appendix G)
n = total soil porosity	1-Pb/Ps	EPA 1996
b = soil-specific exponential parameter		EPA 1996 (Table A-2)
Ks = saturated hydraulic conductivity (m/yr)		EPA 1996 (Table A-2: Silty clay loam)
Ps = soil particle density (kg/L)		TtEMI 2003 (Appendix G)
K = aquifer hydraulic conductivity (m/yr)		TtEMI 2004 (Appendix E)
ii = hydraulic gradient (m/m)		TtEMI 2004 (Appendix E)
I = infiltration rate (m/yr)		Seasoil infiltration model
d = mixing zone depth (m)	Equation 12	EPA 1996
L = source length parallel to groundwater flow (m)		TtEMI 2004 (Figure 4-2)
da = aquifer thickness (m)		TtEMI 2004 (Appendix E)

EPA 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. July.

TtEMI 2003. Remedial Investigation Report, Lockwood Solvent Groundwater Plume Site. June.

TtEMI 2004. Feasibility Study Report, Lockwood Solvent Groundwater Plume Site. July.